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Study of photoconductivity in PbSe Films

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1. INTRODUCTION

Studies on the photoconducting properties of lead salt (PbS, PbTe, PbSe) films are going on for a long period to probe into the fundamental mechanisms of photoconductivity Uptil now, the various models suggested, namely (1)Numbers Model (Moss 1955) (2) Barrier-modulation Model (Slater 1956) (3) Majority Carrier Model (Petritz 1956) cannot uniquely define the photoconducting properties. However, the essential role of oxygen envisaged in the models is contradicted by the results by Zubkova (1974) who concludes that the photosensitivity of PbS films is primarily associated with carrier cocentrations. Yasuoka and Wada (1970, 1974) in a series of papers on photoconducting PbSe films have tried to explain their observations by *Shunt Path model* The influence of shunt path on the sensitivity of the film has not yet been properly understood. Dutta *et al* (1975) have observed that the PbSe films can be sensitized and desensitized by heating in vacuum (10^{-5} torr) without exposing the film to air after deposition. They have observed that the photoconducting decay is significantly fast when measured in situ In this paper, we report the results of our measurements on the temperature variation of photoconductivity and photoconductive decay of PbSe films prepared under controlled conditions The measurement of thermally stimulated current carried out with some of the films indicated the presence of a number of trapping states of different trap depths

2 EXPERIMENTAL

The samples were prepared by subliming PbSe powder from a molybdenum boat on clean pyrex glass slides in a vacuum of the order of 10^{-5} torr. The average thickness of the deposits was determined by the method of weighing for the samples on which no measurements were done in situ For those films on which in-situ measurements were done, the thickness on the film was calculated by a theoretical formula given by $t = km \cos\theta/(\pi r^2 \rho)$ where t = thickness of the film, m = Mass of the material taken in the evaporation boat; r = Distance between boat and the substrate; ρ = Density of the material; θ = Angle between radial distance and the line joining the centre of the evaporation boat and any point on the substrate θ is generally taken as zero for calculating the average thickness because r is large and the area of deposition is small The thickness calculated in this way was compared with the values obtained by the method of weighing for blank experiments. In the present investigation the thicknesses of the films were kept between 1000Å and 4000Å for which the photoconducting behaviour of films remained practically unaffected provided these are not exposed to air.

The resistance of the sample was measured by a simple circuit connecting in series a voltage source, the sample and a standard resistance The current in the circuit was determined by measuring the voltage drop, across the standard resistance, by a Philips microvoltmeter (GM 6020) and the resistance of the sample was then calculated by measuring the voltage drop across it.

The measurements were carried out in a specially designed cryostat, which could be be kept at any desired temperature besutween 150°*K* to 300°K, for long time for the completion of the measurement. The temperature variation of dark conductivity was carried out while heating the films from 150°K to 300°K, and the measurements were done twice in each case. In order to avoid undesirable heating, the films were illuminated for about one minute only at a time so as to allow to attain their maximum photoconductiivty at a given temperature (Fig. 1). The photoconductive decay was then measured by shutting off the

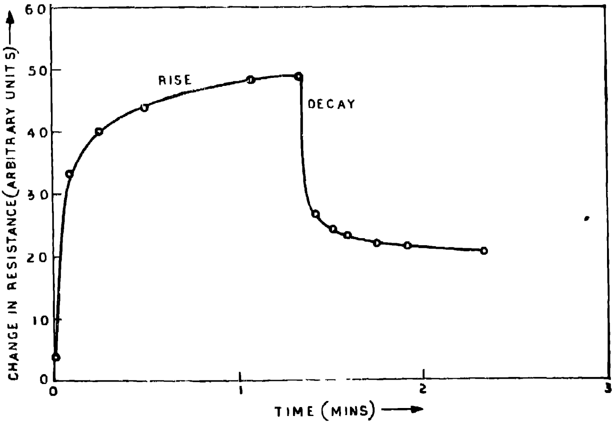
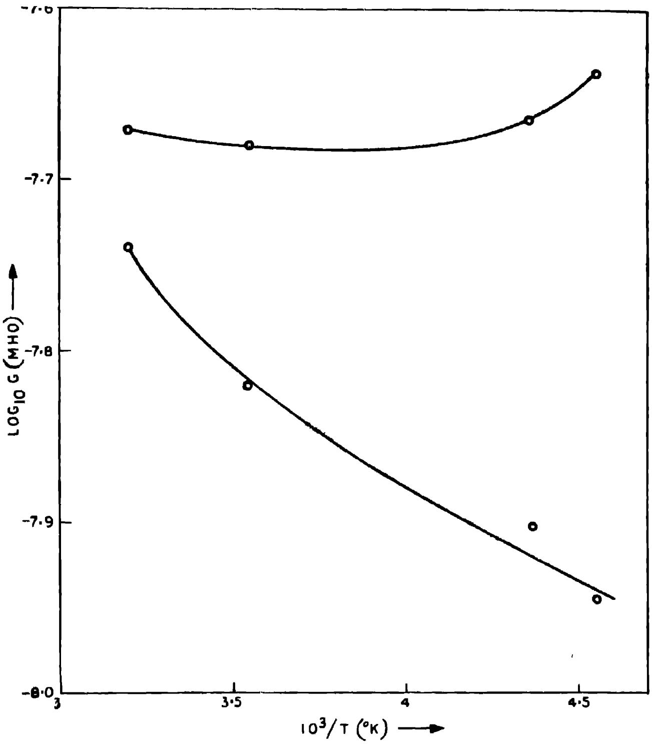


Fig. 1. The growth and decay of photoconductance.

illumination for a period of about four minutes. The temperature of the film was then raised and once again the changes in its conductivity under illumination measured at the higher temperature. The procedure was continued until the room temperature (300°K) was reached. The illumination in all cases was maintained constant. The conductivity of the films under illumination at different temperature was obtained from the maximum value of conductivity attained under the constant illumination used in this experiment. For the measurement of TSC, the films after thermal cleaning (i.e heating up to 300°K so as to remove the effect of the trapped carriers) were cooled in darkness to 150°K; the films were then illuminated for about five minutes by the light source of same intensity as was used for other experiments. The films after illumination were then steadily heated in dark and the changes in conductance of the films noted with rise of temperature. For the insensitive films, i.e. those which show practically no photoconductivity, the temperature variation of conductivity was measured for the sake of comparison with the behaviour of photoconducting films

3 Results and Discussion

PbSe films as deposited were found to be n-type and these can be converted into p-type by heating in air at about 200°C for about two hours The gradual change in the nature of majority charge carrier by heat-treatment in air is known



Figs. 2, 3. Temperature variation of conductance in dark and under illumination.

for PbS-like photoconducting films in general. PbSe films deposited and heat-treated in vacuum show little or practically no photosensitivity. Heating such films in air induces photoconductivity as the films become effectively less n-type; the photosensitivity is found to be maximum for a particular film when it is in the neighbourhood of the condition of maximum resistivity (i.e. about to change over from n-type to p-type). The photosensitivity of the films decreases gradually

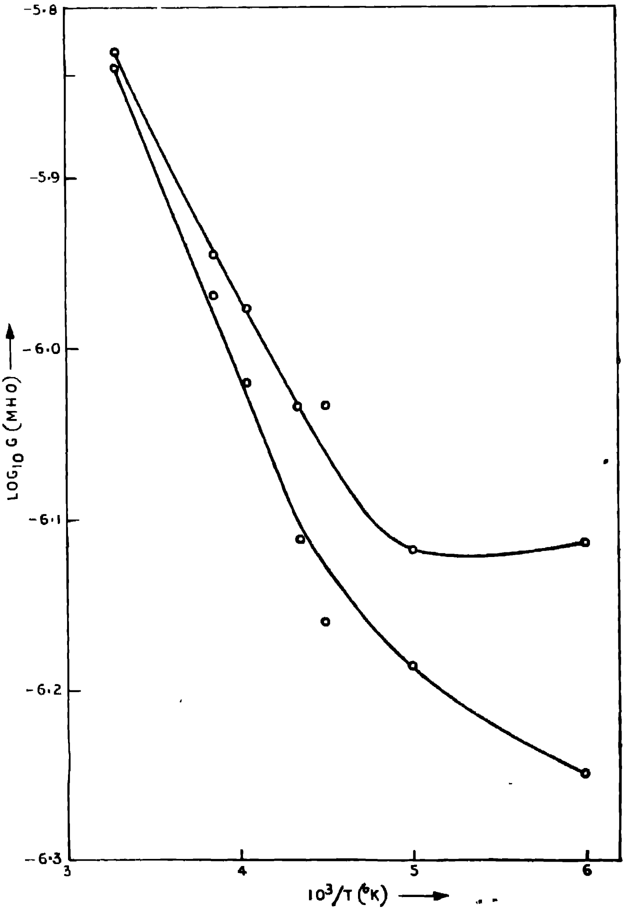


Fig. 3

with increase in the period of heating which makes the films progressively more p-type and conducting. Thus the general nature of the behaviour of PbSe films studied here agrees closely with that reported for lead chalcogenide films

The temperature variation of dark conductance of some of the films and their photoconductance under constant illumination at different temperature are shown in figures 2, 3. The temperature variation of dark conductance can be considered to be near exponential for a small range of temperature around 300°K, but it deviates from exponential variation at the low temperature for the films; conduction through shunt path or similar mechanism seems to be mainly responsible for current flow through the film at low temperature. At ordinary temperatures, this part of the current is negligible compared to the conduction current through the crystallites In other words, the temperature variation of the conductance of the films in the temperature range studied here appears to consist of two parts, one of which is practically temperature independent (or very slowly varying with temperature) and the other varies exponentially with temperature i e $g = g_1 + g_2 \exp(-E/KT)$

The photosensitivity of the films increases significantly, (figure 4a, b, c) in general, at low temperatures; the nature of temperature variation which is

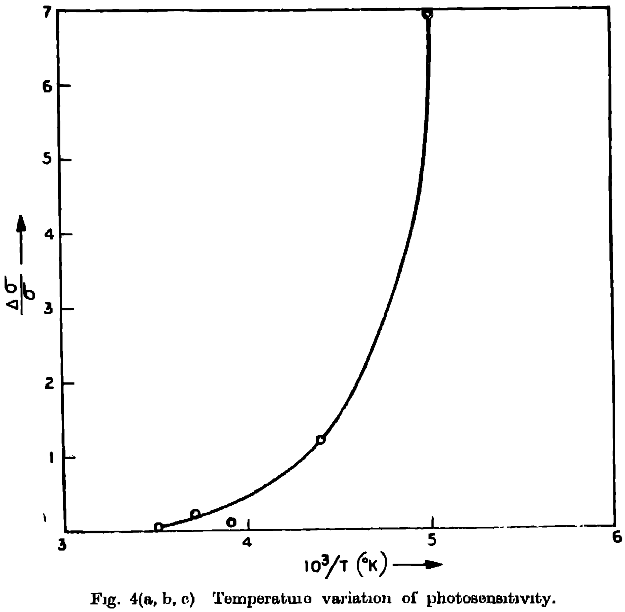


Fig. 4(a, b, c) Temperature variation of photosensitivity.

very rapid in some of the films, depends on the thermal and other history of the film. X-ray diffraction studies have revealed the presence of oxides of lead and density of lattice defects (viz. microstrain) in the photosensitive films; the relative extent of oxidation and density of lattice defects have been found to vary from sample to sample. Further detailed work is necessary before a significant correlation between photosensitivity and its temperature variation and the results of X-ray diffraction studies can be established. The temperature variation of photosensitivity indicates that both of the mechanism—changes in carrier concentration and modulation of barrier height—are effective in the photoconductive

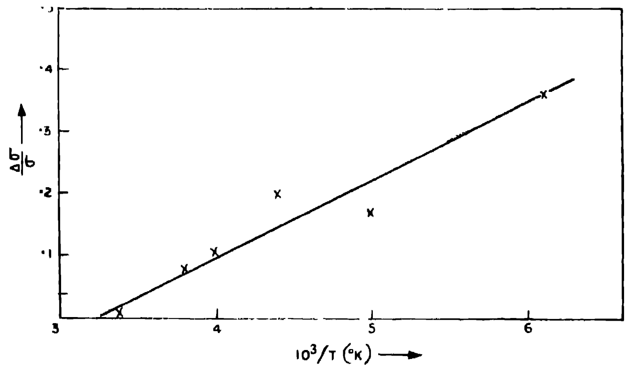


Fig. 4b

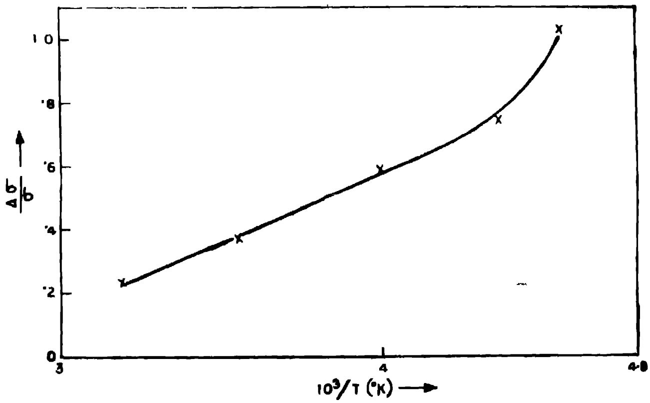


Fig. 4c

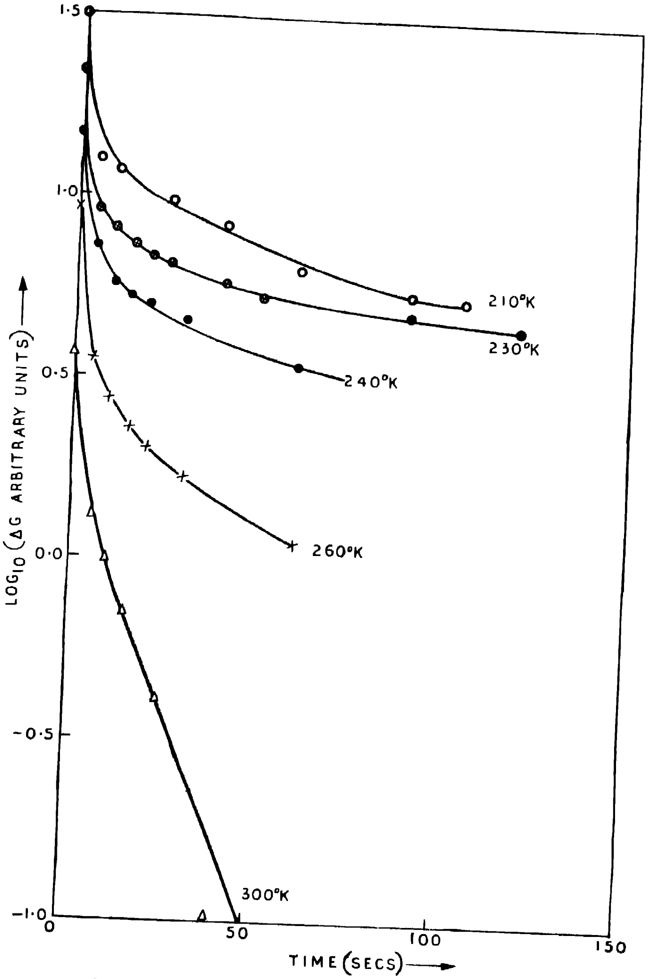


Fig 5(a, b) Decay curves for different temperatures.

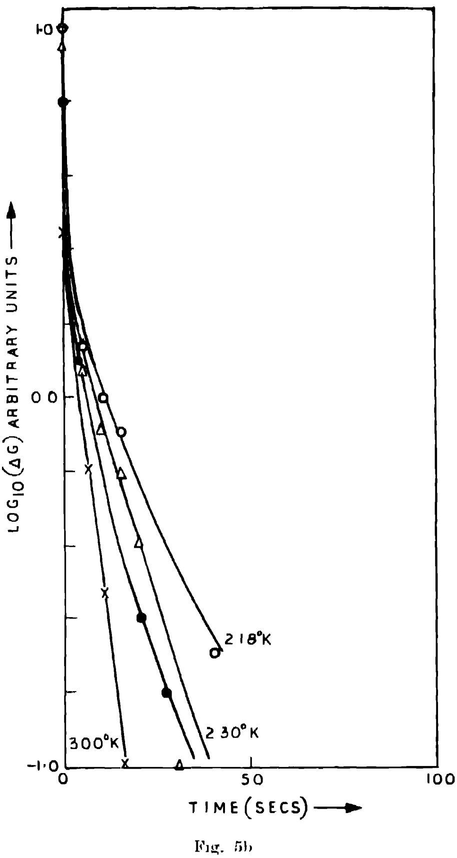


Fig. 5b

processes of such films, the relative importance of the two mechanisms depending on the nature of the film and its temerature The nature of the results are in general agreement with those reported for PbS films

The growth and decay of photoconductance shown in figure for typical films indicate the presence and importance of trapping mechanism in these films The curves measured for different temperature within a comparatively small range (figures 5a, 5b) can be fitted into a exponential variation with a single trap depth i e within a small range of temperature it follows the equation given by $\tau = a$

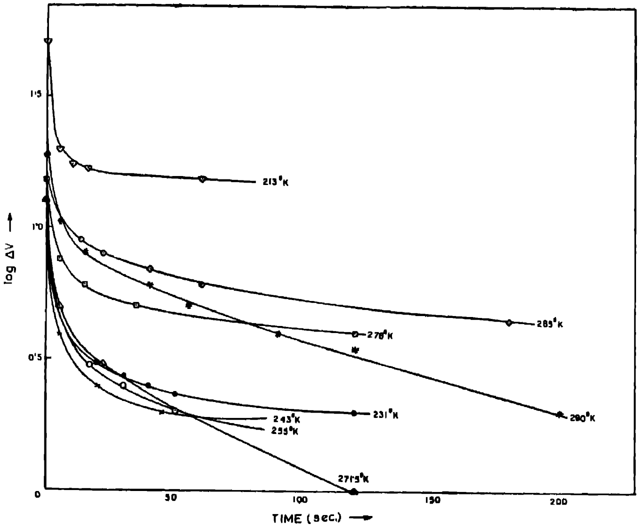


Fig 6 Temperature variation of decay curves.

$\exp(-E/KT)$ There are however films which show a wide distribution of decay curves over a wide range of temperature (figure 6). This is reflected in the thermally stimulated current measured for such films after exposing them to radiation at low temperature (figure 7).

Further investigations are in progress for a quantitative analysis of the results.

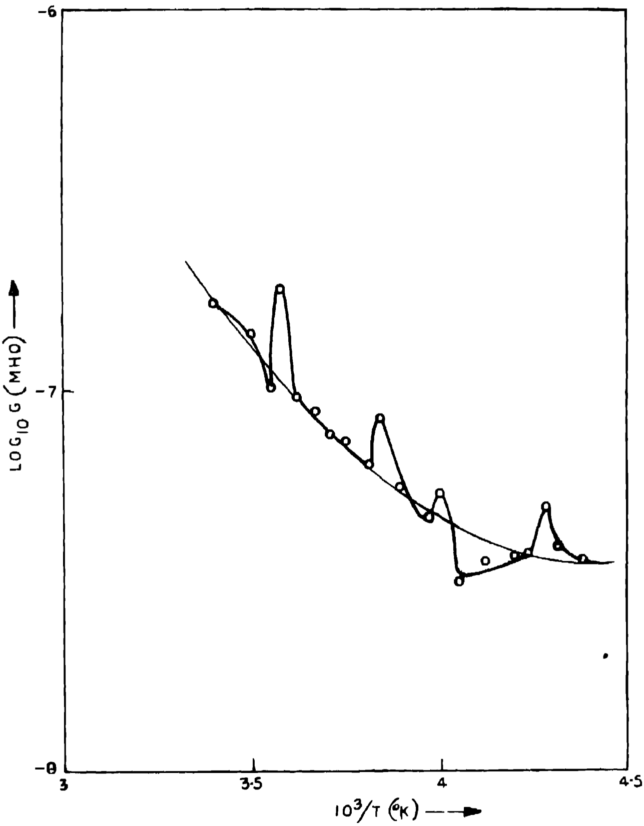


Fig. 7 Thermally stimulated current for a typical film.

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